Optical tweezers for velocity mapping in microfluidic channels

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Abstract: We have successfully applied an optical tweezer for mapping the velocity profile in microfluidic channels. The velocity profiles for a straight and a u-shaped microfluidic channels were determined by direct measurment of the Stokes force.

OCIS codes: (350.4855) Optical tweezers or optical manipulation; (280.4788) Optical sensing and sensors;

Ever since optical trapping was discovered and the first experimental observation was reported in 1970's [1, 2], the ability to manipulate microscopic objectives has promised great potential. However, it was not until after 1986 when A. Ashkin and S. Chu demonstrated the first optical tweezer [3] that optical trapping successfully found its major application in biology [4]. Since then, a substantial number of scientific discoveries have been reported using this technology [5-7]. Nevertheless researchers are continually looking for wider applications of this powerful tool in other branches of sciences and technologies.

Microfluidics deals with fluids that flow at micrometer scale and couples with numerous fields such as physics, life sciences, chemistry and medicine by miniaturized fluidic devices and superior performance over conventional macroscopic systems [8]. In order to understand the dynamics of the fluid in a microfluidic system, which differ from those in macroscopic environment, great effort has been put into mapping of velocity profiles inside devices however most methods, such as scalar image velocimetry [9] and laser doppler velocimetry [10] are not really compatible with microfluidic environment. The most commonly used method of fluidic velocity characterization in a microfluidic device is microparticle image velocimetry [11], however there is the potential that the dense suspension of tracer particles will have a negative influence on the fluid to be detected. It is therefore desired that a method tailored specifically for microfluidic systems be developed. Due to the non-invasive nature of optical tweezers, its high sensitivity as well as the ability to achieve localized sensing, the marriage of optical tweezers and microfluidics seems to be a perfect match.

Here we present a method of applying optical tweezers to directly measure the velocity profile inside microfluidic channels of different internal geometries. The transverse velocity profiles across a straight and a u-shaped microfluidic channels were measured and compared with computational fluid dynamic (CFD) simulations.

In our experiments, microfluidic devices of straight and u-shaped geometries (shown in Fig. 1. and 2 respectively) were fabricated in polydimethyl siloxane (PDMS) by soft lithography. The templates of the microfluidic channels were produced in laminated films on glass substrates with the channel patterns fabricated by laser cutting. The template for the straight channel device was fabricated by an amplified femtosecond pulse laser and the template for the u-shaped device was fabricated by a CO_2 laser. Afterwards the PDMS polymer was cast onto the templates and cured at before being peeled off and bonded by plasma treatment (20 seconds in O_2 plasma) onto cover slips. The PDMS layers were then hole-punched and bonded with connectors at the inlets and outlets.

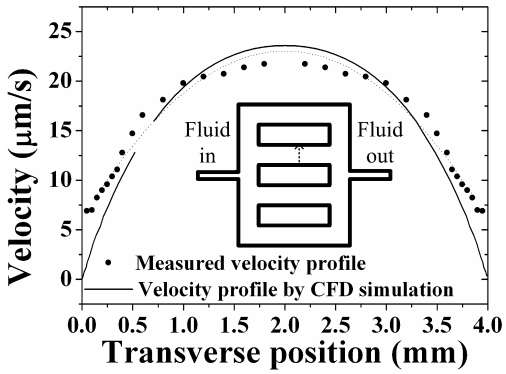

Fig. 1. Schematic illustration of a microfluidic device with straight channels with the experimental and simulated velocity profiles across the transverse direction of one of the channels (see the dashed line);

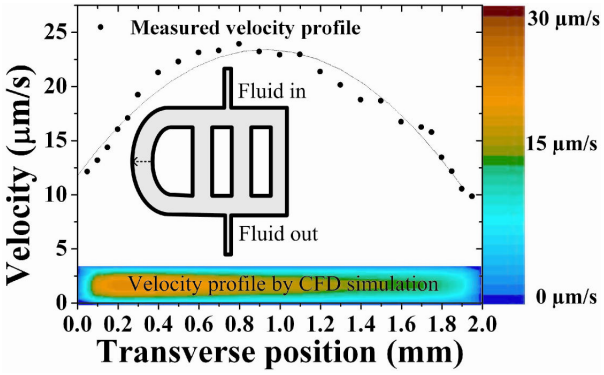

Fig. 2. Schematic illustration of a microfluidic device with a u-shape channel with the experimental and simulated velocity profiles (the insert) across the transverse direction of the u-shaped channel (see the dashed line);

After fabrication of the microfluidic devices, they were mounted on a translation stage and connected to a peristaltic pump which pumped a dilute aqueous solution of microspheres. A femtosecond pulse laser beam (30 mW,

800 nm, 82 MHz, 90 fs) was focused into the microfluidic channels by a 1.2 NA water immersion objective to generate the optical tweezer. The fluid velocity profiles across the transverse direction of the channels (see the dashed lines in Fig. 1 and 2) were then characterized by measuring the optical trapping force required to trap the microspheres. The fluid velocity is determined by

$$\upsilon_{fluid} = \frac{Qn_2P}{F}, \tag{1}$$

Where υ_{fluid} is the fluid velocity, Q is the transverse trapping efficiency, n_2 is the refractive index of the water, P is the threshold laser power. The Stokes force, F is defined as

$$F = 6\pi\eta_L r\upsilon, \tag{2}$$

Where η_L is the viscosity coefficient of the water, r is the radius of the microsphere and υ is the velocity of light in vacuum. From equations (1) and (2) the fluid velocity can be directly correlated to the threshold optical trapping power.

As shown in Fig. 1, the measured velocity profile in the straight channel agreed well with the simulated velocity profile and showed a parabolic shape. For the u-shaped channel (Fig. 2), the asymmetric velocity profile is believed to be a result of the "race track" effect due to the bend in the internal geometry of the channel.

In summary, we have demonstrated the application of femtosecond pulse laser optical tweezing to directly map the fluid velocity in microfluidic channels of different geometries by directly measuring the threshold Stokes force on trapped microspheres. The measured velocity profiles were confirmed by CFD simulations and showed high accuracy.

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